Detection of the Climate Change Signal in the Hydrological Record

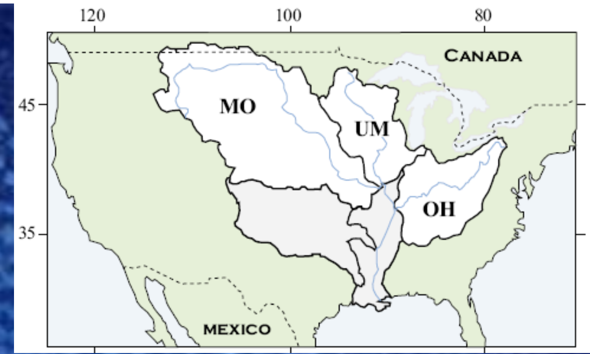
Fourth Annual California
Climate Change Conference

Ed Maurer

Santa Clara University

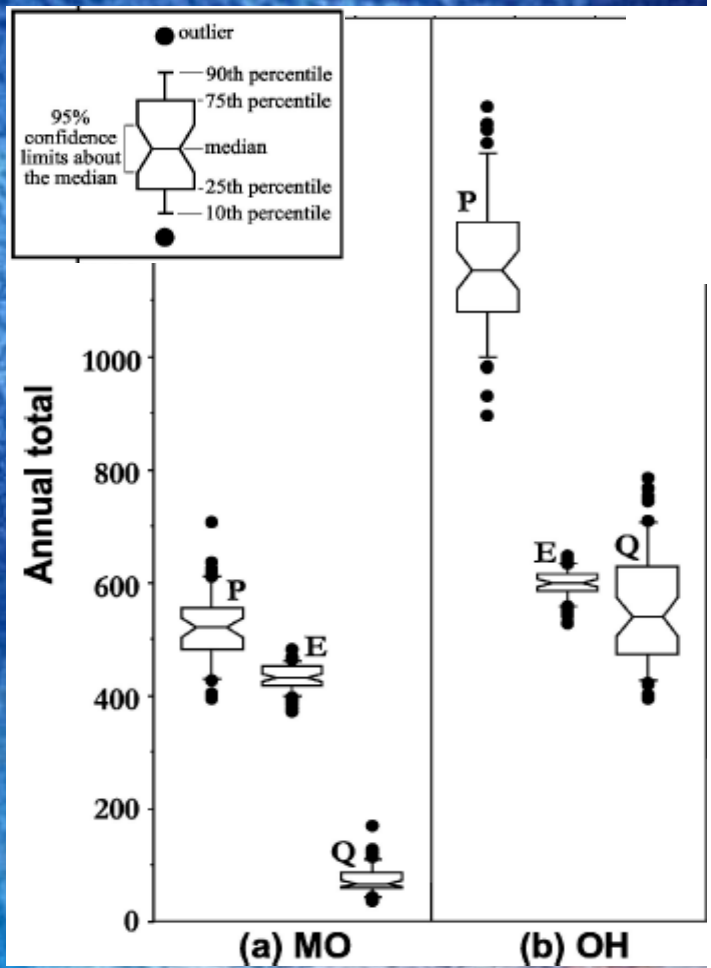
September 10, 2007

What affects detectability of changes in hydrology?



- Interannual/decadal variability
- Trend/Shift magnitude
- Confidence Level
  - at what probability of erroneously detecting a change are we willing to take action?
- Variable of interest
- Character of basin (e.g. water- vs. energy-limited, snow dominated)

MO: w ≈ 0.15 OH: w ≈ 0.45

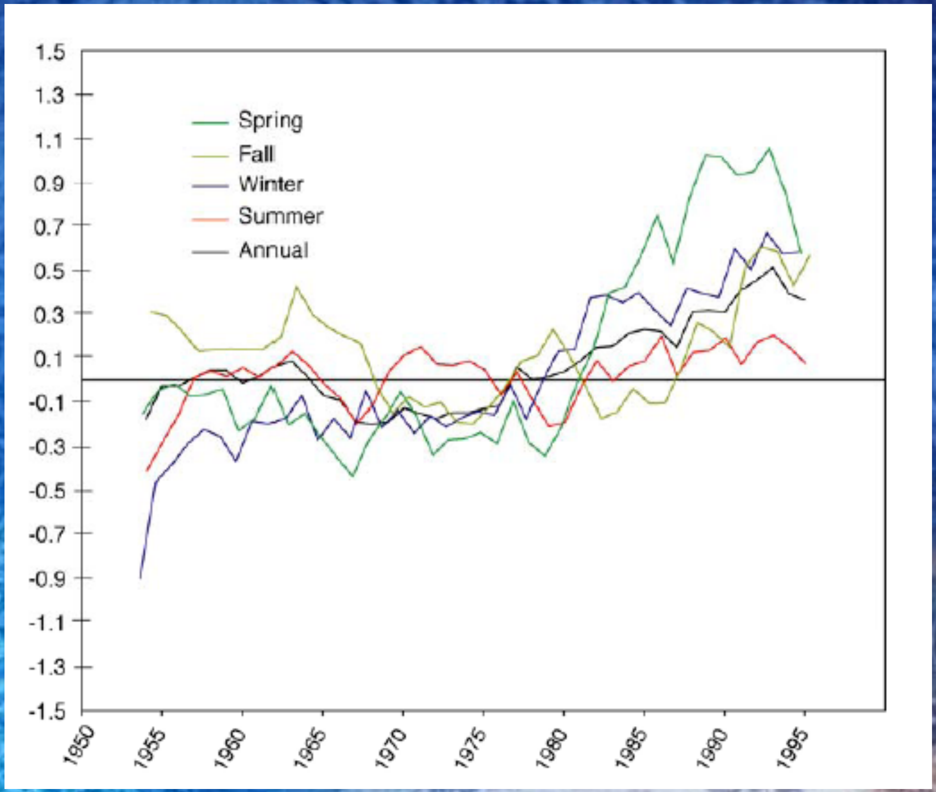


•For both basins, 21st century P, E trends significant, but not Q
•E trend most detectable (46 yrs), but observations sparse, paradoxical
•Annual Q trend not detectable for centuries
•Seasonal trends more easily detected

Ref: Ziegler et al., 2005, Climatic Change

What Climate Changes Have We Seen in California?

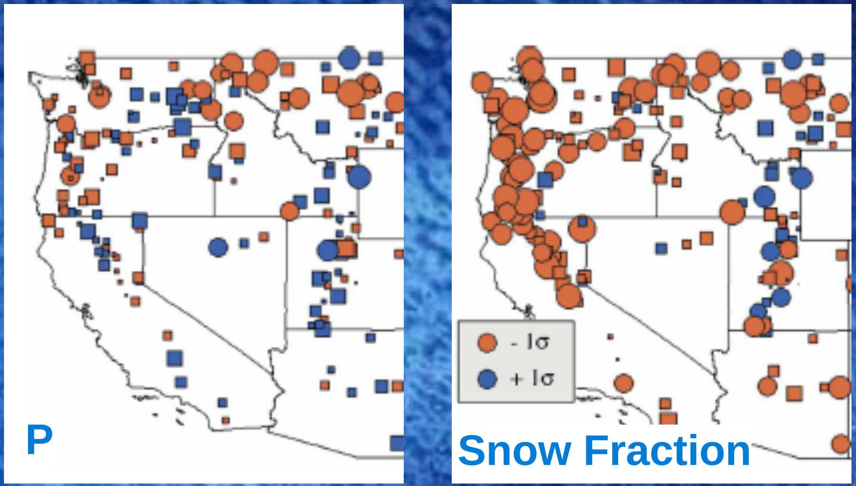
- Annual T increase over 50 years of 1°F
- Exceeds natural variability (at 90%)
- Larger warming in Spring and Winter
- Generally insignificant (positive) precipitation changes



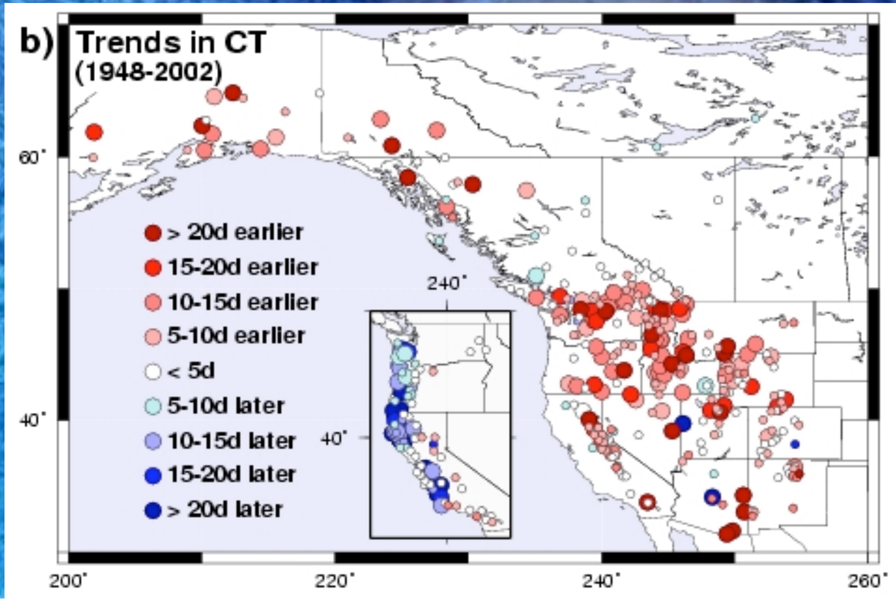
Ref: Cayan et al., 2006, Climate Scenarios For California, CEC-500-2005-203-SF

Hydrologic Impacts of late 20th Century Changes

- Trends in precip and winter snow fall shown
- Reduced snow is response to warming during winter wet days (0-3°C)
- Trends in stream flow timing shift of 1-3 weeks earlier over the past ~50 years
- Timing shift dominated by changes in snowmelt-derived streamflow, partially attributed to warming



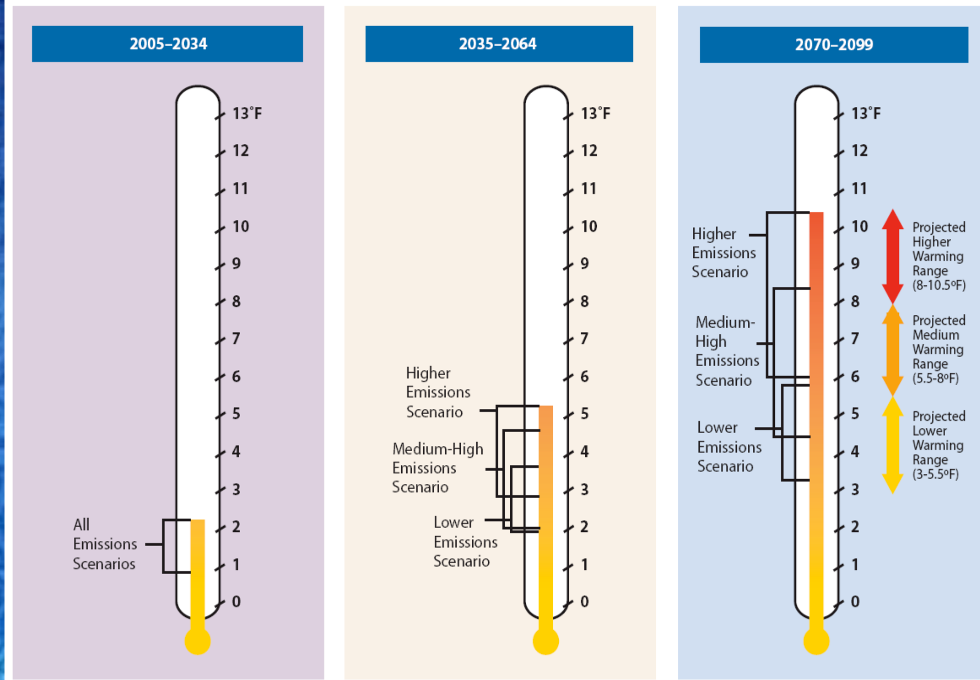
Ref: Knowles et al., 2006, J. Climate 19.

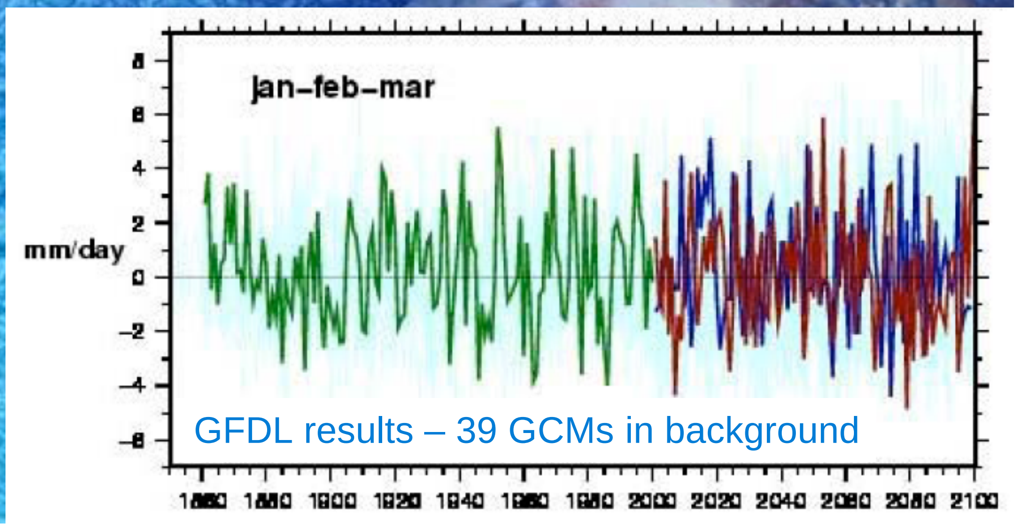


Ref: Stewart et al., 2005, J. Climate 19.

What Climate Changes Are Projected?

- CA average annual temperatures for 3 30-year periods
- Amount of warming depends on our GHG emissions at end of 21st century.
- Summer temperatures increases (end of 21st century) vary widely:
  - Lower: 3.5-6 °F
  - Higher: 6-10.5 °F
- No model consensus on precipitation

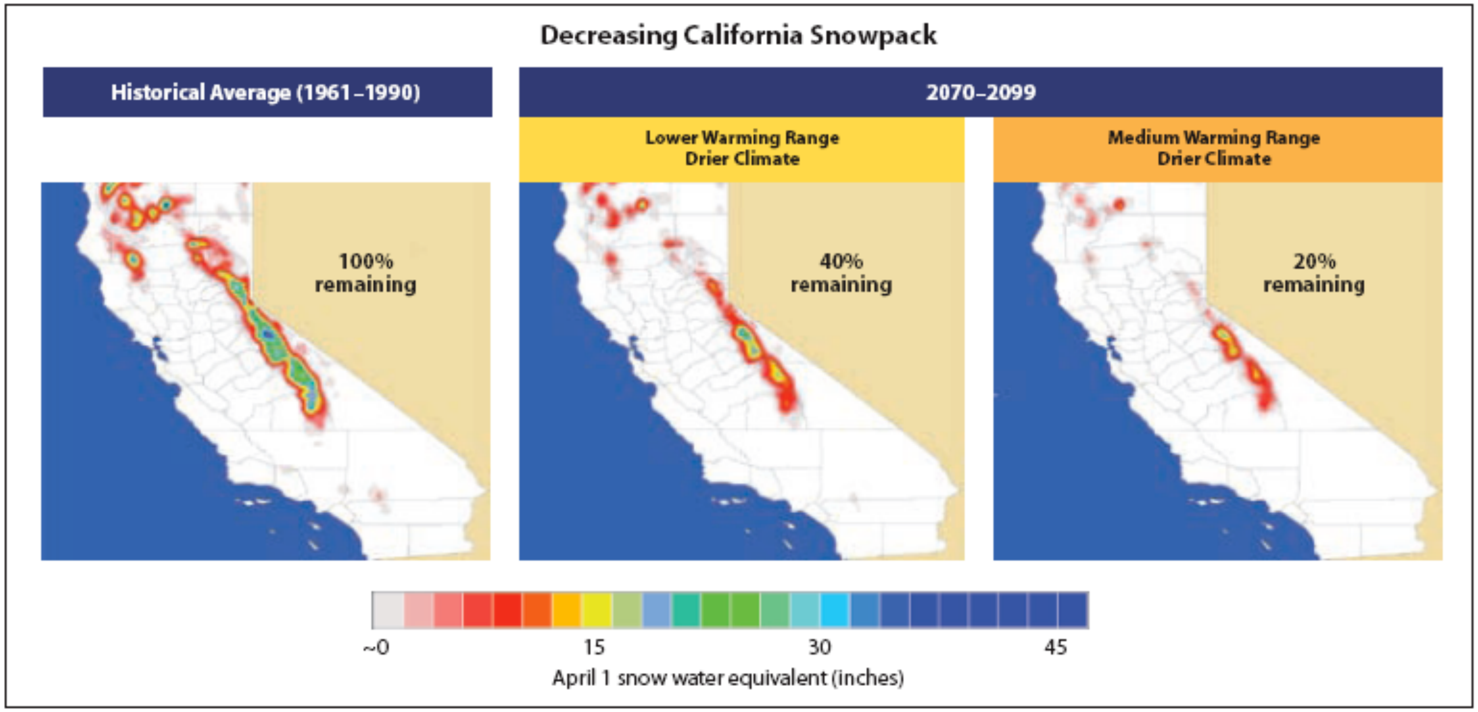




Ref: Luers et al., 2006, CEC-500-2006-077 and Cayan et al., 2006, CEC-500-2005-203-SF

Projected Impacts: Loss of Snow

- Snow water in reserve on April 1
- Change (Sacramento-San Joaquin basin):
  - -12% to -42% (for 2035–2064)
  - -32% to -79% (for 2070–2099)



Ref: Luers et al., 2006, CEC-500-2006-077

Projected CT Shifts at reservoir inflows - from 22 GCM runs

Projected Changes in Timing Relative to 1961-1990 (from Maurer, 2007)

Basin	ΔCT under Mid-High Emissions (A2), days			ΔCT under Low Emissions (B1), days		
	Early 21st Century	Mid 21st Century	End of 21st Century	Early 21st Century	Mid 21st Century	End of 21st Century
Feather R.	**-14**	**-18**	**-23**	**-10**	**-11**	**-17**
American R.	**-19**	**-23**	**-31**	**-17**	**-20**	**-26**
Tuolumne R.	**-9**	**-20**	**-33**	**-10**	**-14**	**-23**
Kings R.	**-9**	**-21**	**-36**	**-8**	**-16**	**-24**

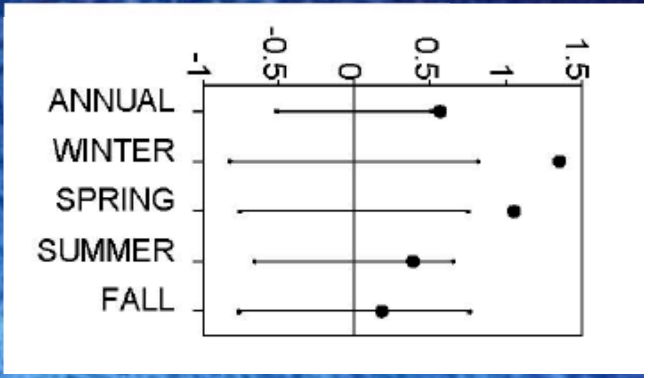
- ΔCT at major inflow points to CA water system: Oroville, Folsom, New Don Pedro, Pine Flat
- Mean of GCMs shows no annual P change
- Small shift in P from spring to winter
- CT shift mostly due to T increases
- All shifts exceed 99% confidence as being different from zero

Attribution of streamflow timing changes

- Can these past (or projected future) CT shifts be attributed to external forcing (like GHG increases)?
- When (or at what temp increase) might they?
- Which basins or regions will be most vulnerable (where is detectability enhanced)?

Determining Natural Variability

- Similar to method used by Cayan et al., 2006 for past seasonal temperature changes
- Use long GCM control run to estimate internal (non-forced) variability

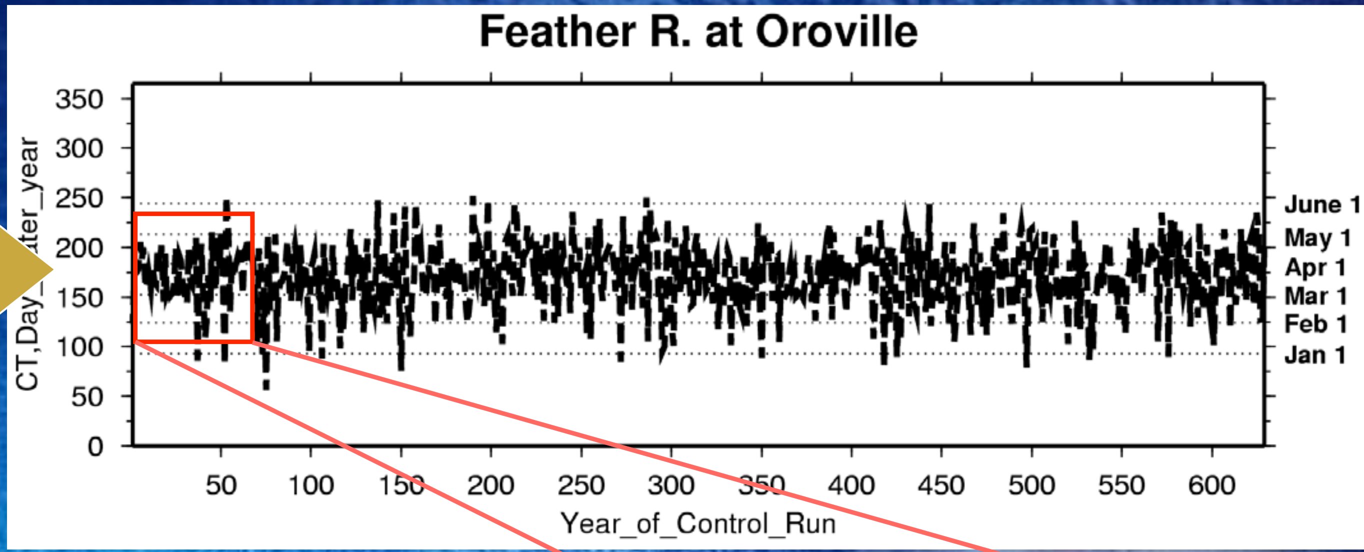


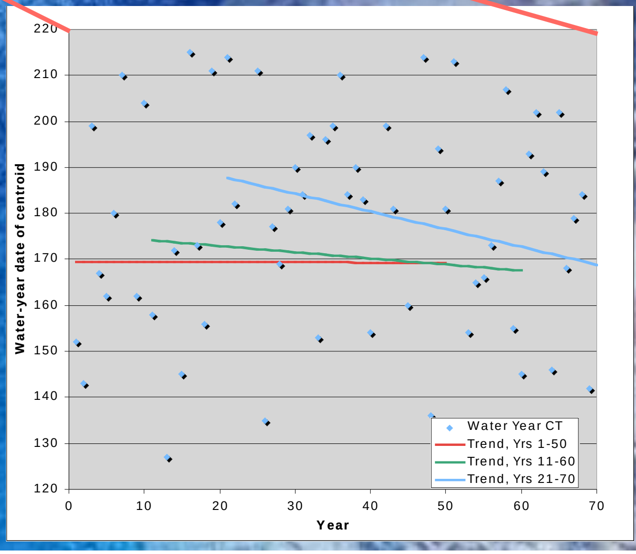
GCM Preparation:

- Bias correct using 20th century simulation and observations (1950-1979)
- Downscale to input to VIC model

Natural variability in 50-year streamflow timing trends

629 years of control PCM simulated CT dates for Feather R.





- Find 50-year linear trends
- Repeat, offsetting by 10-years
- 58 trend segments

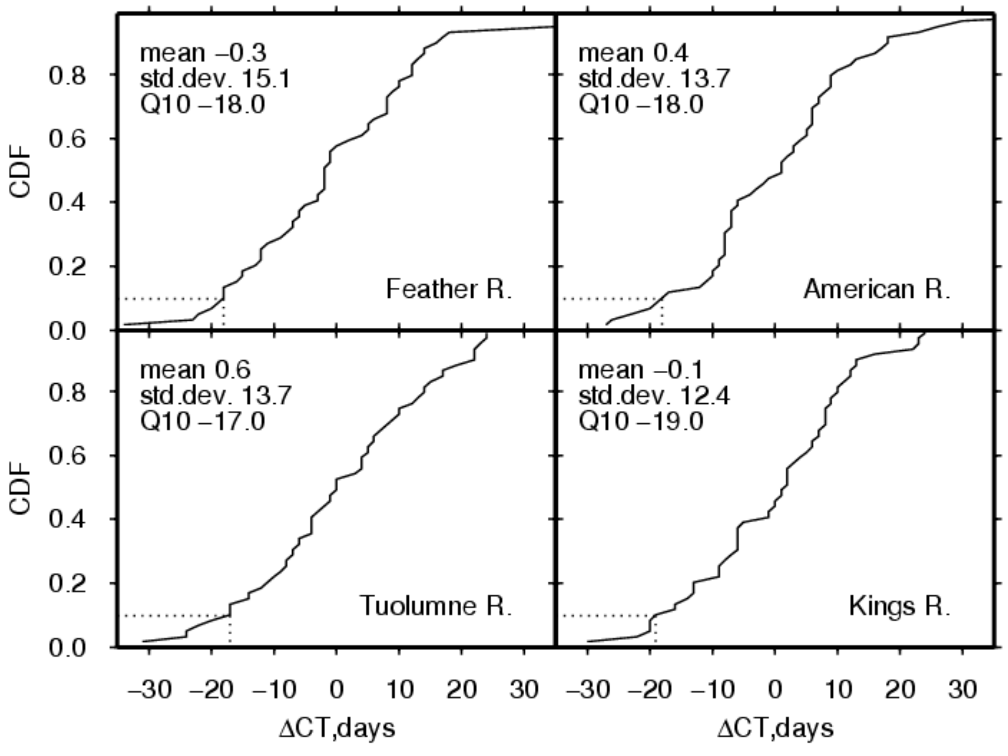
50-Year Trend Distributions

- Cumulative distribution functions for CT trend (days/50 years) for PCM control run.

- Q10 is the shift to earlier in the year only exceeded by 10% of the control trend segments.

- Q10 varies from 17-19 days for these sites.

- A 50-year trend in CT would need to shift 17-19 days earlier to achieve confidence level of 90%



How big are historic trends at these four sites?

Site Name	Feather R at Oroville	American R at Folsom Dam	Tuolumne at New Don Pedro Res	Kings R. at Pine Flat Dam
Timing Shift, days (- indicates earlier)	+1	-9	+4	+2

Much smaller than 17-19 days earlier

- *Basins include rain dominated area*
- *Timing less sensitive to historic temperature trends than at smaller headwater areas.*

- *When will projected changes become confidently attributable to external forcing?*

Detection of Externally-Forced Projected CT Shifts at Key Sites

Projected Changes in Timing Relative to 1961-1990 (from Maurer, 2007)

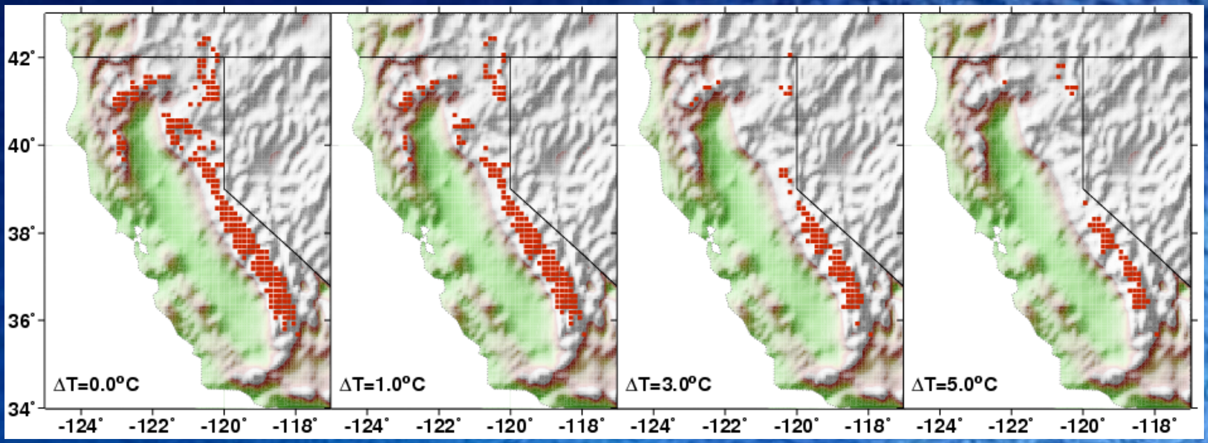
Basin	ΔCT under Mid-High Emissions (A2), days			ΔCT under Low Emissions (B1), days		
	Early 21st Century	Mid 21st Century	End of 21st Century	Early 21st Century	Mid 21st Century	End of 21st Century
Feather R.	-14	-18	-23	-10	-11	-17
American R.	-19	-23	-31	-17	-20	-26
Tuolumne R.	-9	-20	-33	-10	-14	-23
Kings R.	-9	-21	-36	-8	-16	-24

Q10 values for different trend lengths

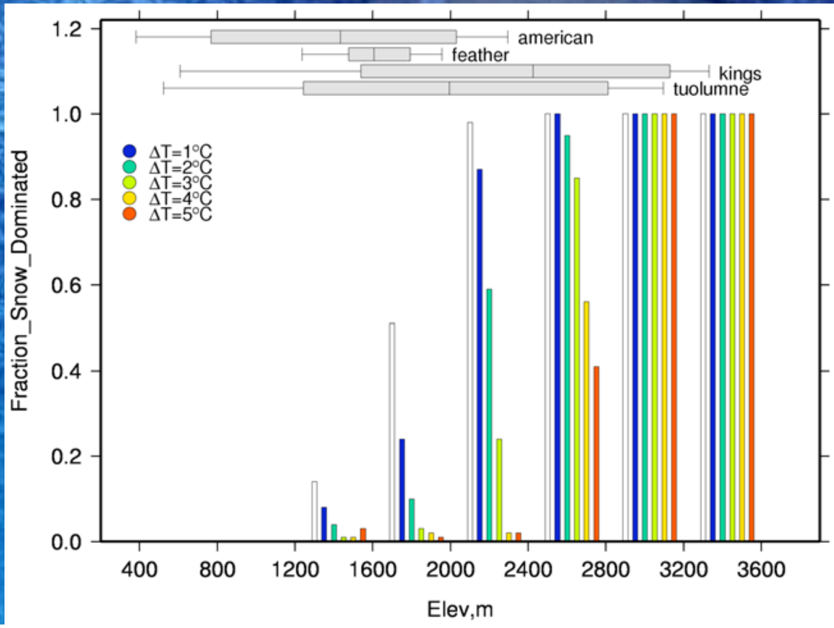
Basin	50-year	80-year	110-year
Feather	-18	-16	-15
American	-18	-16	-15
Tuolumne	-17	-10	-8
Kings	-19	-11	-7

- Attribution limited for early 21st century (ΔT≈1°C)
- By mid-century (ΔT≈1.7-2.2°C), high confidence CT shifts, esp at high elevs
- Less influence of P variability at high elevations
- Higher Emissions Accelerate Detectability and Attribution

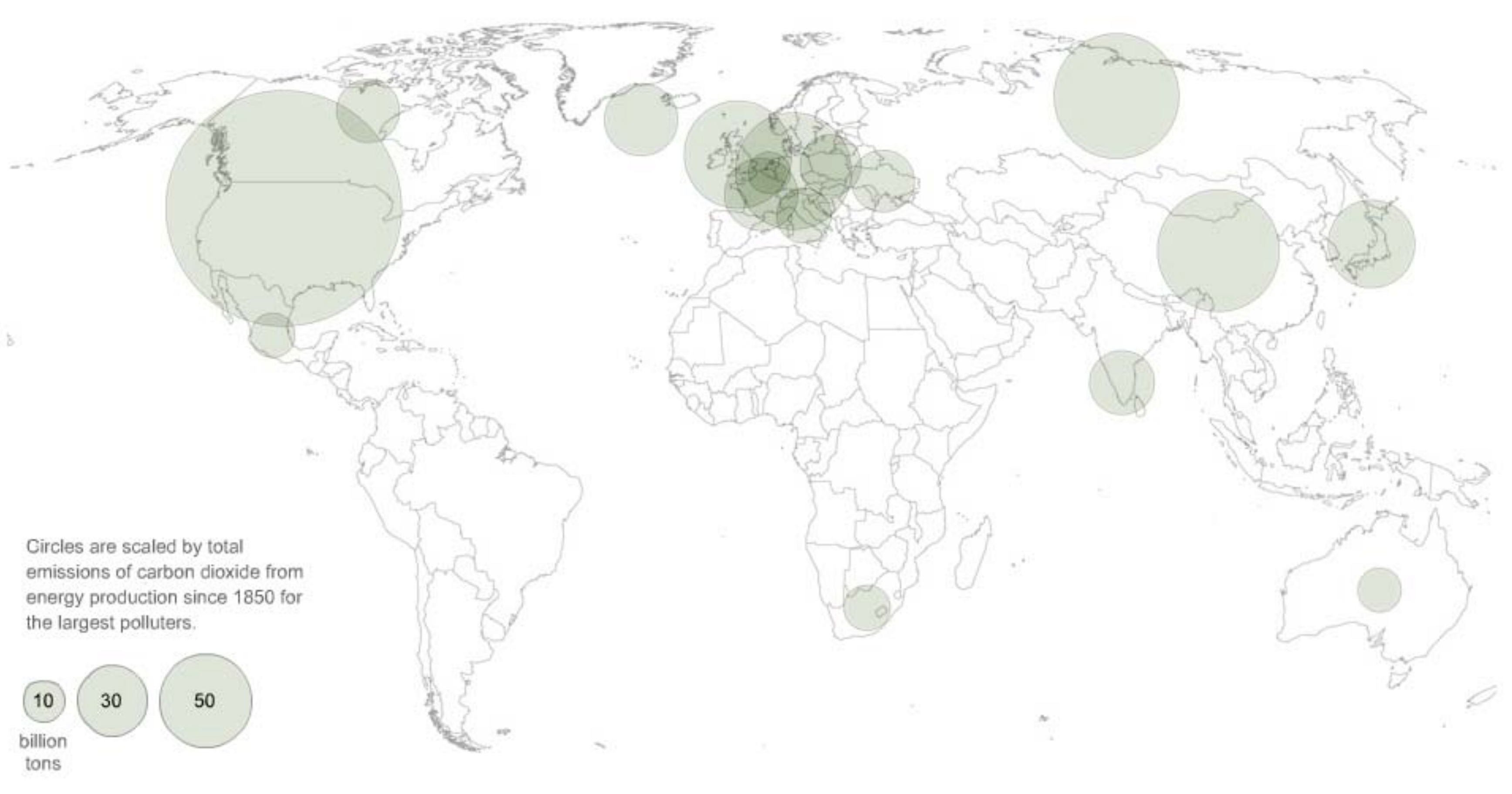
Change from snow to rain dominated



- Snow dominated areas are > 1600m
- Change to rain dominated hits 1600-2000m areas with 1°C increase
- 2400-2800 m regions affected with Δ T>3°C
- A low emissions future leaves most area >2400m snow dominated
- Higher emissions affect up to 2800 m



Source of cumulative CO_2 emissions

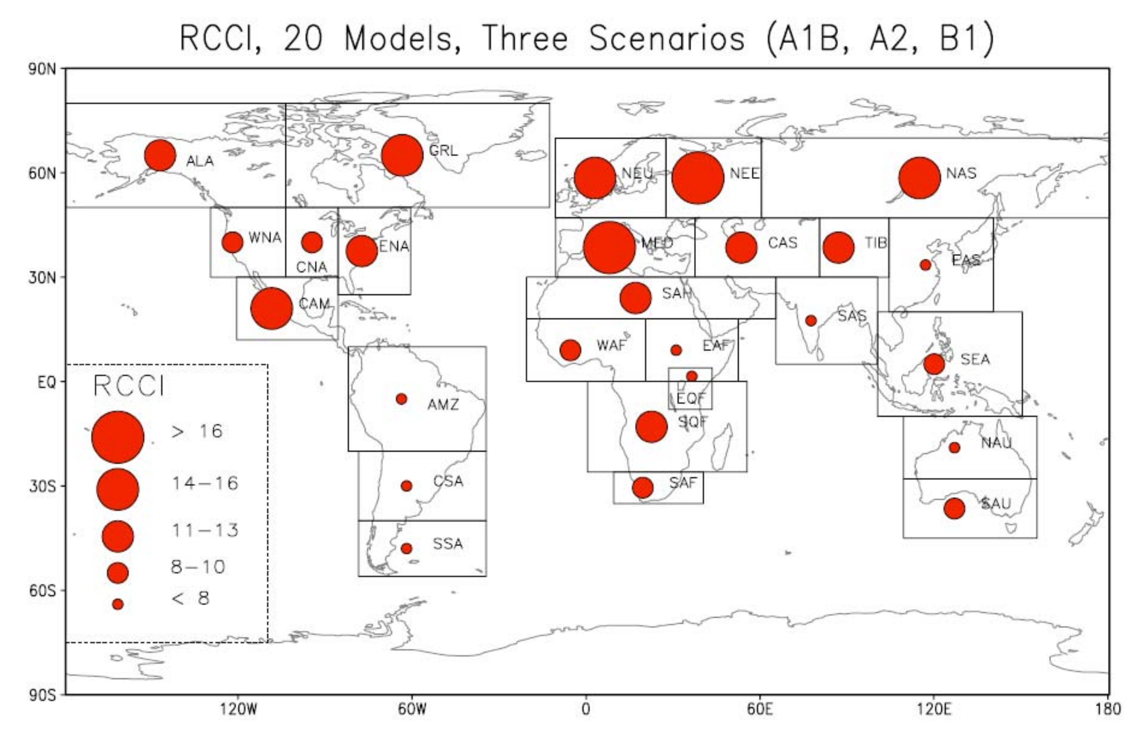


Sources: World Resources Institute; Intergovernmental Panel on Climate Change Working Group I; CIESIN; Deborah Balk, CUNY; NOAA; Shishmaref Erosion and Relocation Coalition; Monsanto; Thames Estuary 2100; BAST; BBC; Degrémont; Multiplex Group; peer-reviewed scientific papers

James Bronzan and Shan Carter / The New York Times

Regional Responses to Climate Change

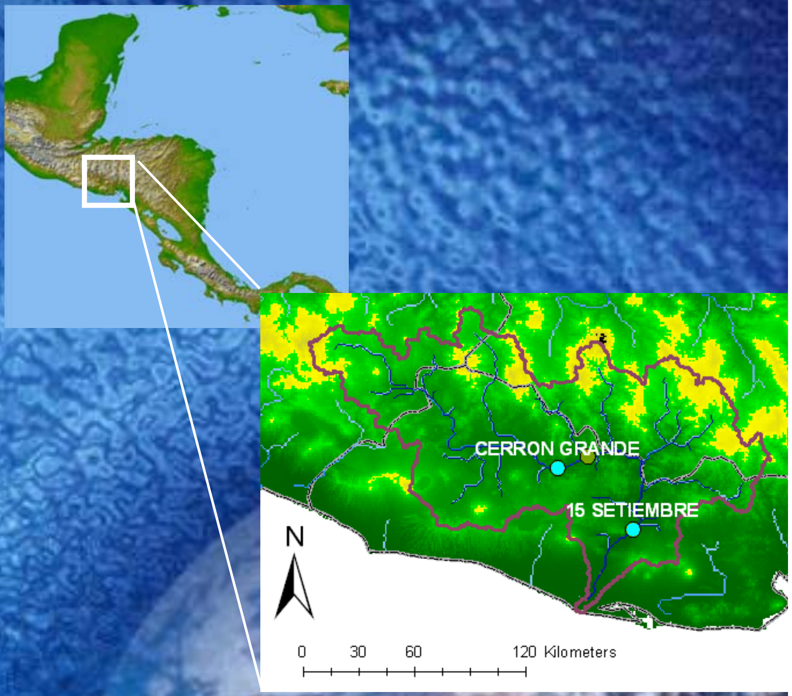
- RCCI Index quantifies regional response to changes in mean and variability of precipitation and temperature
- Central America is most prominent tropical hot spot
- Primarily because of projected decreasing precipitation and increasing variability
- CA is "intermediate"



Ref: Giorgi, GRL, 2006

Hydrologic Impacts – Rio Lempa

- Highly significant (detectable) changes before mid-21st century
- By 2070-99, Precipitation drops by ~5% (B1) to ~10% (A2), high confidence before mid-21st century
- Rio Lempa reservoir inflows projected to drop by 13% (B1) to 24% (A2)
- Drop in firm hydropower generation capability may range from 33% to 53% near the end of the 21st century.



IPCC: Effectiveness of adaptation efforts depends on the availability of general information on vulnerable areas and projected impacts.

Summary

- Most detectable changes in CA will be temperature-driven
- Attribution of hydrological changes will be possible by mid-21st century
- Warming associated with different emissions produces distinct futures by mid-21st century, affecting detectability and attribution
- Models of assessing vulnerabilities can help with adaptation elsewhere

Thank You to Supporting Institutions

Santa Clara University

UC MERCED

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UCSD